Document ID: EDF-4397
Revision ID: 0
Effective Date: 02/12/04

Engineering Design File

PROJECT FILE NO. 23833

Grout Selection Criteria and Recommendation for the OU 7-13/14 In Situ Grouting Early Action Project

Idaho National Engineering and Environmental Laboratory

Form 412.14
10/9/2003
Rev. 05

ENGINEERING DESIGN FILE

EDF No.: 4397   EDF Rev. No.: 0   Project File No.: 23833

1. Title: Grout Selection Criteria and Recommendation for ~~Beryllium Encapsulation~~ the OU 7-13/14 In Situ Grouting Early Action Project - DSD 2-11-04

2. Index Codes:
Building/Type N/A   SSC ID N/A   Site Area 098

3. NPH Performance Category: ______ or ☒ N/A

4. EDF Safety Category: ______ or ☒ N/A   SCC Safety Category: ______ or ☒ N/A

5. Summary:

This Engineering Design File delineates the selection of grout to perform in situ grouting of 15 beryllium block burial sites at the Subsurface Disposal Area (SDA) at the INEEL's Radioactive Waste Management Complex (RWMC).Carbon-14 and tritium has been detected coming from the Be blocks. Release of these contaminants is caused by corrosion of the block. Grout applied in situ to these blocks may minimize this corrosion by stopping water intrusion and thus slow contaminant release and movement. In situ grouting involves underground injection or placement of "grout" type material to isolate the waste from infiltrating water, decrease the corrosion of the Be blocks, decrease the release of carbon-14 and tritium, and possibly contain their movement.

The grout selection criteria and evaluation developed here is a summary derived from previous laboratory and field measurements of in situ grouts applied to the SDA transuranic waste. These results are then applied to the encapsulation of buried Be block waste. A value-engineering meeting was held to evaluate the criteria and grout evaluation and the results have been incorporated into this document. Specific treatment requirements for a Be block waste site include a combination of physical barriers to prevent water from getting to the blocks and not precluding their possible future retrieval. For encapsulation of the Be blocks, Waxfix grout should be superior to other INEEL-tested grouts.

6. Review (R) and Approval (A) and Acceptance (Ac) Signatures:
(See instructions for definitions of terms and significance of signatures.)

	R/A	Typed Name/Organization	Signature	Date
Performer/ Author	N/A	Peter Shaw	Peter Shaw	2-5-04
Technical Checker	R	Tom Bechtold	[signature]	02/05/04
Approver	A	Dave Nickelson	David F. Nickelson	2/5/4
Requestor	Ac	Dan Crisp	Dan E. Crisp	2/5/4
Doc. Control	Ac	Juana Cruz ~~Mary McQuiston~~	Juana Cruz	2/12/04

7. Distribution: (Name and Mail Stop) F. Webber, D. Crisp, D. Keller, P. Shaw, D. Nickelson, K. Shropshire, F. Ireland, E. Thompson, M. McQuiston

8. Does document contain sensitive unclassified information? ☐ Yes ☒ No
If Yes, what category: N/A

9. Can document be externally distributed? ☒ Yes ☐ No

10. Uniform File Code: 6102   Disposition Authority: ENV1-h-1
Record Retention Period: See list 9

11. For QA Records Classification Only: ☐ Lifetime ☒ Nonpermanent ☐ Permanent
Item and activity to which the QA Record apply:

12. NRC related? ☐ Yes ☒ No

ENGINEERING DESIGN FILE

EDF No.: 4397 EDF Rev. No.: 0 Project File No.: 23833

1. Title: Grout Selection Criteria and Recommendation for the OU 7-13/14 In Situ Grouting Early Action Project

2. Index Codes:
   Building/Type NA SSC ID NA Site Area 098

10. Uniform File Code: 6102 Disposition Authority: ENV1-h-1
    Record Retention Period: See List 9

11. For QA Records Classification Only: ☐ Lifetime ☒ Nonpermanent ☐ Permanent
    Item and activity to which the QA Record apply:

12. NRC related? ☐ Yes ☒ No

13. Registered Professional Engineer's Stamp (if required)

CONTENTS

TABLES

This page is intentionally left blank.

Grout Selection Criteria and Recommendation for the OU 7-13/14 In Situ Grouting Early Action Project

1. INTRODUCTION

This Engineering Design File delineates the selection of grout to perform in situ grouting of 15 beryllium block burial sites at the Subsurface Disposal Area (SDA) at the Idaho National Engineering and Environmental Laboratory's (INEEL's) Radioactive Waste Management Complex (RWMC) (Shropshire 2004). Five specific locations in two soil vault rows and 10 in three trench areas contain Be blocks. The blocks occupy a volume of about 9 m^3 (2,378 gal) and the blocks within their steel canal baskets occupy 48 m^3 (12,682 gal) (Mullen 2003). This waste was originally disposed as low-level radioactive waste, but further studies indicate it may be defined as remote-handled transuranic waste (Mullen 2003, Abbot 2004). Carbon-14 and tritium have been detected coming from the Be blocks. Release of these contaminants is caused by corrosion of the block (Olsen 2003).

Grout applied in situ to these blocks may minimize this corrosion by stopping water intrusion and thus slowing contaminant release and movement. In situ grouting involves underground injection or placement of "grout" type material to isolate the waste from infiltrating water, decrease the corrosion of the Be blocks, decrease the release of carbon-14 and tritium, and possibly contain their movement. The grout selection criteria and recommendation developed below are a summary derived from previous laboratory and field measurements of in situ stabilization materials (Shaw 1997) applied to the encapsulation of buried Be block waste. A value-engineering meeting was held to evaluate the criteria and grout evaluation and the results have been incorporated into this document. Minutes of the meeting are attached as Appendix A.

2. BERYLLIUM BLOCK ENCAPSULATION OBJECTIVES

In situ grouting (ISG) consists of below ground isolation of buried Be blocks without their removal. The primary effectiveness objective is to prevent water from getting to the Be blocks. Secondarily the grout application should facilitate possible subsequent retrieval, isolate contaminants from the environment (specifically carbon-14 coming from the blocks), reduce subsidence potential over the waste to prevent water ponding and subsequent infiltration, and be repairable, should hydraulic isolation be compromised.

The primary implementability objective is to apply the grout using pressure jet grouting and encapsulating the target waste safely while controlling contamination during application. Secondary objectives are obtaining experienced vendors, equipment, and grout in a short time framework.

The effectiveness objectives for in situ grouting early action contribute to reduce the risk posed by carbon-14. Though ISG does not change the physical or chemical form of the Be blocks themselves, it can change the chemistry that causes their corrosion, by preventing water contact with the blocks. This is accomplished by decreasing the bulk permeability and increasing the bulk density of the existing buried waste site. This limits release and transport of carbon-14 and tritium.

Aspects of the Be block recommendations stem from the waste form performance criteria specified by the Nuclear Regulatory Commission *Technical Position on Waste Form* for ex situ-produced low-level waste (NRC -1991), and *Proposed Waste Form Performance Criteria and Testing Methods for Low-Level Mixed Waste* (Franz 1994). An important part of the performance criteria stems from the laboratory and field experience at the SDA dealing with waste stabilization material testing for TRU (Loomis 1995–2001).

3. BERYLLIUM GROUT CRITERIA

In past studies, a variety of grouts have been considered for in situ grouting of buried debris waste at the SDA. These evaluations are partially applicable to in situ grouting of Be blocks at the SDA. Table 1 shows some of the implementability features of these grouts grouped by chemical makeup (organic and inorganic). Many of these grouts were lab-tested and evaluated using a variety of criteria from NRC solidification of nuclear power plant waste. Based on their performance against the NRC criteria, grouts were chosen for field-testing with SDA simulated buried waste at the INEEL site.

An initial grout down-selection was conducted based on past successful testing of high-pressure jet grouting emplacement in SDA simulated buried wastes. This criterion meets the implementability objectives of the Be block encapsulation grout. Since these grouts must have been applied by in situ jet grouting at the INEEL, in full-scale buried waste or soil, they should be readily implementable for Be blocks within the time frame of the Be block project.

This past field-testing on simulated buried waste is the primary screen to determine grouts applicable to the Be blocks in the INEEL soil vaults and trenches. Past testing of in situ grouts have been directed primarily toward treating TRU buried waste at the INEEL; thus, grouts are compatible with INEEL buried waste and soil properties. The site/waste/soil properties such as soil porosity, composition, buried waste density, and debris inhomogeniety are deemed sufficiently similar to that of the Be blocks to preclude the necessity of field testing to demonstrate implementability.

3.1 Implementability

As discussed above, the primary implementability criterion to screen the grouts is: has the material been successfully jet grouted at the INEEL in simulated waste conditions? By limiting selection to grouts applicable for TRU in situ buried waste stabilization at the INEEL, most of the implementability factors for Be blocks in LLW at the INEEL are met and field implementation can be performed without further field testing.

Applicable grouts for in situ high-pressure jet grouting of soil/waste materials will use techniques developed and demonstrated at the INEEL. The uncured grouts chosen all have hydraulic properties, i.e., be a pumpable liquid or liquid-like material and have a viscosity of 50 centipoise or less. The size of the particles in the suspension is less than 3 mm to prevent nozzle plugging. Grout and additives are suspendable in the hydraulic state for pumping and have a set time of no less then 120 minutes.

Table 2 presents additional implementability criteria developed to address specifics of the Be block encapsulation project. Table 3 summarizes the evaluation of the down-selected grouts against these criteria. Criteria in Table 2 are numbered to facilitate the presentation of the information in Table 3.

It is assumed that the test stabilization materials will be applied using high pressure grouting equipment. Cementitious grouts have greater density then organic grouts and benefit more from the high kinetic energy of a jet grouting application in INEEL claylike silt soils. All of the cementitious grouts are denser then the organic grouts and in field applications have been applied at higher pressure and tend to form a slightly larger column under tightly packed or undisturbed soil conditions.

Chemical Category	Chemical Base	Trade Name	Company	Cost	Set/Gel time (hrs) (2)	Viscosity (Centipoise) (1)	Density (g/ml)	Category Comments
					Organic (Carbon)			
Organic Polymers-thermoset	Acrylate	AC-400	3M	High	1-2	1-3	1.2	Mixing critical, sometimes nuisance odor, moisture may affect set. Heat generated during set. **3M CONCRETE RESTORER (methacrylates) field demonstrated at INEEL.**
	Methacrylate	4R		High	1-2	1-3	1	
	Vinyl-Ester	DERA-KANE		High	1-2	5	1	
	Styrene	470-45		High	1	100		
	Polyester-Styrene	ATLAC		High	1-2	300	1	Unsuccessful field demonstration at INEEL.
	Polyacrylamide	FLOPAAM	Pfizer	High	1	5-40		
	Epoxy	Carbaray	Carter Tech	Med	1-			
Organic Polymers-thermo plastic	Asphalt			Low	2-	100	0.9	Thermal 60-300°C application difficult, moisture may drive off VOCs in waste. Most tested for ex situ mixed waste applications. Not demonstrated for in situ subsurface walls or floors. **WAXFIX field demonstrated at INEEL.**
	Polyethylene			Med	3-	70	0.9	
	Wax (melting)	WAX FIX	Carter Tech	High	4-	10	0.8	
	Wax (emulsion)	MONTAN		Med	24-	3	0.9	
				norganic (Phosphorous, Calcium, Iron, Silicon)				
Phosphates	Magnesium or Iron based Apatites	Enviroblend	American Minerals Steller	Med	2-6	100-1000	1.7	Not demonstrated underground. Used in road construction. May be difficult due to two-component mixture. Heat generated during set in massive application may be excessive.
		Phoscrete		Med	1-2	100-1000	1.7	
Calcium	Portland Cement	Type I-II, V or H	Ash Grove	Low	2-	20-1000	2.2	**Cemetitious grouts (TECT, Portland Type H, I-II, G-ment, Microfine) are the most Field Demonstrated ISG material at the INEEL.** Routine to apply. The cemetitous category is preferred in most applications based on versatility, experience, contaminant containment and cost.
	Portland-Hematite	TECT	Carter Tech	High	4	50-10000	2.7	
	Portland-Silicon	Microfine	US Grout	Med	2-	50-1000	2.2	
	Portland-GBFS	G-MENT	Technology Venture	Med	2-	50-1000	2.1	
Iron oxide	Hematite		INEEL	Low		50-10000	1.4	Unsuccessful INEEL field demonstration. Leach resistant only.
Silicates	Sodium Silicate			Med	4-	3-30	1.2	Desiccation cracking but self-healing properties. Apply in saturated zone. Easy to apply, demonstrated in construction and in sandy soils (Hanford and BNL).
	Bentonite			Low				
	Colloidal Silica	LUDOX	Dupont Dow Corning -	Med	4-	50	1.3	May be too thick to Jet Grout.
	Poly Siloxane	PSX – 10		High		500-2000	1.2	
	Ground Blast Furnace Slag (GBFS)			Low	6-	4-40	2.1	Ground Blast Furnace Slag can be used in place of Portland Cement.

Note: Bold text indicates successful field demonstration.
1. Upper range of viscosity and gel time varies with temperature, water and/or additives
2. Set time dependent on ionic setting agent, and/or pH of setting agent
3. Cost High >5$/gal, Medium 1-5$/gal, Low < 1$/gal

Table 2. Implementation criteria used to evaluate field-tested in situ grouts.

#	Criteria	Measurement
1	Material compatibility with Be blocks in baskets and disturbed INEEL damp soil	No adverse reaction during implementation with soil, moisture or Be blocks
2	Heat generation, minimal heat given off during application	Calorimetry, final temperatures not to exceed 100°C
3	Hygienically safe and non-hazardous, exhibiting minimal hazardous dust/vapor releases during application, not flammable, corrosive, pyrophoric, explosive, reactive, no listed substances	Vapor levels below TLV ignitibility <100°C, pH between 4 and 9 or corrosion rate of matrix <10 $g/m^2 \times d$ in DI water, no toxic metals, listed organics, reactivity, A-E List (primarily organics)
	Additional interim stabilization/retrievability criteria	
4	Retrievable, fines generation minimized if disturbed	90% reduction over base case of retrieval with no agent
	Repairable, As placed properties can be restored at a later date	Past industry/construction experience with grout repair
	Criteria considered separate from technical criteria	
5	Cost – Within project budget	Effectiveness in application to Be blocks should justify higher volumetric cost

Table 3. Evaluation of selected grouts – implementability criteria.

Implementability Criteria	Cost	Compatibility With:						Interim Actions		
		Jet Grouting					Be Blocks	Retrieval		Ability to Repair
Criteria Number (from Table 2)	6	Go/no Go	Go/no Go	Go/ no Go, 3	1	2	1	4	4	5
In Situ Agent	High Med Low	Year of Field Test	Gallons in Field Test	Ease of High Pressure Application	Viscosity cp	Set Temp °C	Penetration of Be Blocks	Fines Generated upon Retrieval	Shielding of Radiation Field	
3M Concrete Restorer	High	1995	1156	Premature set impossible before component mixing, some nuisance fumes	5	92–115	May penetrate Block Fine Structure	The most retrievable grout tested	Beta shielding limited gamma	Repaired by injecting crack fillers i.e. more of the same grout
Waxfix	High	1997	1227	Natural Lubricant, Premature set easily prevented by heat tracing	10	60–82	Should penetrate Block Fine Structure	Not tested Should be similar to thermoset	Beta shielding limited gamma	Mostly easily repaired simply by reheating ground
Portland Type I Portland Type H TECT US GROUT GMENT	Low Low High Med Med	1986, 1988 1994, 1995 1997, 1998 2001 2001	4847 1436 1167 141 1296	Filter caking and bubble formation may occur	20 20 50	45–60	Should encapsulate entire block	90% less fines than non-cement base case	Beta and gamma shielding	Repaired by injecting crack fillers- more grout or concrete restorer
High = >$5/gal Med = 1–5$/gal Low = <1$/gal										

One of the down-selected organic grouts (Waxfix) may be applicable to emplacement by lower pressure systems and easily repairable due to thermoplastic properties. During the field trial it was noted that the wax stayed molten for several days and pliable for several weeks. As long as wax was molten it continued to permeate into the soil. The test site experienced further sealing from this wax flow and could be repaired in the future by simply heating the site and adding more wax as needed.

Material compatibility deals with the nature of the waste and soil, in this case Be blocks, INEEL fine claylike soils, and low level waste debris type wastes that might surround them. Dust generation becomes a factor only if retrieval is desired after grouting. This has been assumed to be a general heavy equipment excavation similar to what has been demonstrated at INEEL GEM project. Regulatory and safety compliance, such as vapor and heat generation, were obtained from manufacturer specification or demonstrated in the lab and field tests.

3.2 Effectiveness

This section discusses criteria addressing effectiveness: the ability of the substance, once applied, to mitigate contaminant release by resisting water penetration, gas evolution, and contaminant leaching. Some of the criteria applicable to the Be block sites are similar to those criteria used in the past to evaluate grout effectiveness associated with TRU waste; however, additional criteria were also added based on the Be block site conditions and the value engineering meeting, such as restricting gas generation and compatibility in a high radiation field.

Table 4 provides general effectiveness criteria that have been considered during past INEEL ISG studies. Effectiveness related to the Be block application will be inferred for many of the long-term durability parameters, hydraulic performance derived from material properties, and natural analog experience.

Most of the grouts listed in Table 1 have been leach tested for metal and TRU-contaminant surrogates. The affect of non-cementitious grouts on carbon-14 release and compatibility with the matrix (beryllium) have not been lab- or field-tested. Cementitious grouts have been tested and used on tritium-containing waste in the nuclear power industry.

Since carbon-14 is initially released from the Be blocks as a gas, gas permeability is also a consideration. Gas permeability has not been tested in past INEEL grout studies. Although limited data on gas contaminant release might be available for Portland cement (as it relates to ex situ encapsulation of LLW from Nuclear Power Plants, which has limited applicability to in situ grouting), engineering judgment will have to suffice.

In situ grouting effectiveness criteria are considered as matrix criteria or contaminant criteria. For this evaluation, matrix criteria are considered primary and contaminant criteria secondary.

Matrix criteria:

1. Decrease hydraulic conductivity of water and contact of soil with the Be blocks slowing their corrosion

2. Prevent subsidence of trenches or soil vaults, sufficient compressive strength to hold up a future cap

Table 4. Effectiveness criteria to evaluate field-tested in situ grouts.

Performance Criteria	Measurement	Reference Procedure
Resist subsidence from external (environmental) and internal (waste) conditions.	Sufficient compressive strength to hold up cap, >50 psi or within 20 psi of surrounding soil, <20% change in strength after mixing with soil, <20% decrease after a 90-day water immersion	10 CFR 61.56 ASTM C 39
Long-term physical or chemical durability. Grouts should last for 1000 years.	Natural Analog amber, crude oil, limestone. 30 days wet-dry, max. and min. temperature cycling (based on site conditions, application and radioactive decay heat and moisture, environmental temperature range), with 10% waste loading not including soil. Final bulk density greater than soil and waste	ASTM D 1074 ASTM B553, WIPP/DOE-089
Resist leaching; radionuclide, stabilization material.	Radionuclide dissolution-leachability index >6.0, matrix rate of release $<10^{-3}$/yr	ANS 16.1, MCC-3, PCT 40 CFR 261.24
Hydraulic conductivity	Lab hydraulic conductivity of at least 10^{-7} cm/s, that of an EPA clay liner. Field conductivity equal to or less than that of surrounding undisturbed soil.	ASTM D2216 ASTM 1990
Resist biodegradation at site locale under its temperature and moisture conditions (Polymers, wax)	<10% total carbon loss after 300 years	ASTM G21 ASTM G22 (*ref 14)*
Minimal gas generation, chemical, thermal, and radiological	<0.5 moles/ft^3 year <800 moles/ft^3 total	10 CFR 60 NUREG-CR-2333
Resist radiation degradation	>60 psi compressive strength after 10^8 rad gamma	10 CFR 61.56(b) Appendix A

3. Improve physical properties of the surrounding waste materials and waste site in general

4. Long-term durability, have a naturally occurring analog, resistant to radiation, biodegradation

5. Prevent formation or further development of secondary sources of contamination.

Contaminant criteria:

1. Retard leaching of carbon-14 ($C^{14}O_3{}^{-2}$) in the INEEL site environment by physical encapsulation

2. Reduce carbon-14 ($C^{14}O_2$) solubility by chemical reaction

3. Retard gaseous movement for release of carbon-14 ($C^{14}O_2$) source term.

The effectiveness criteria listed above were used to evaluate the field-tested grouts for the Be block application. This evaluation is summarized in Table 5. Performance properties of each grout as both a barrier to water and contaminant release are described below.

3.2.1 Hydraulic Conductivity – Water Intrusion

The lab and field hydraulic conductivity for two of the three field-tested products have been measured. All selected grouts would improve the hydraulic properties of the Be block waste site. Cementitious grouts can improve a field site estimated hydraulic conductivity of 10^{-5} cm/sec one order of magnitude to 10^{-6} cm/sec. Waxfix can improve hydraulic conductivity of a buried waste site by roughly two orders of magnitude to 10^{-7} cm/sec. This is equivalent to that standard set by the EPA of a constructed clay liner. The ability to prevent water intrusion may not transfer to containment of contaminants of gas, but does diminish the corrosion of the Be blocks and thus the gas formation.

3.2.2 Compressive Strength – Subsidence Resistance, Waste Site Physical Properties

The strength of the grout itself to resist deformation and subsidence is typically measured via compressive strength. All the grouts have sufficient strength to support a cap. The NRC has required a minimum of 60 psi to support 20 ft of overlying soil. All the grouts have sufficient strength, even with substantial waste or soil, to exceed 200 psi.

Compressive strength is also a rough measure of the adhesion of the grout to waste. Adherence of grouts to Be has not been tested and is estimated from grout applications on buried waste metals. Based on compressive strength and their chemical reactivity, it is assumed that cementitious grouts will adhere more tightly to Be blocks and their surrounding waste than Waxfix. The Concrete Restorer is specially designed to adhere to mineral substances and is expected to adhere more tightly to the Be blocks than Waxfix.

3.2.3 Be Block Compatibility – Contaminant Leaching, Corrosion Mitigation

Be block compatibility with the selected grouts has not been specifically tested. Both the adhesion of the grout to the blocks and any reaction of the grouts to the blocks are important factors. Corrosion testing in reactor canal water seems to indicate enhanced corrosion at raised pH in a warm aqueous environment (Burnham 1953); however, only corrosion with water contact was observed. Coupon corrosion tests in INEEL soil indicate it is the conductivity of the soil that enhances corrosion—particularly induced from water saturation (Adler 2001, Mizia 2000).

Table 5. Evaluation of selected grouts—effectiveness criteria.

Generic Category	Chemical Base	*Brand Name*	Hydraulic Conductivity (cm/sec)	Field Hydraulic Conductivity (cm/sec)	Compressive Strength (psi)	Reactivity, Corrosion of Be	Natural Analog	Grout Leaching	Contaminant Leaching	Gas Permeability
Criteria #			1	1	2,3	3,5,6,7,8	4	5,	6,7	8
ORGANIC										
Organic Polymers-thermoset	Meth - acrylate	*Concrete Restorer*	10^{-9}	Not Measured	1000–3000	No known reactivity	Amber	Excellent	Fair, additives helpful	Excellent
Organic Polymers-thermo-plastic	Paraffin Wax	*Waxfix*	10^{-9}	10^{-7}	200–400	No known reactivity	Crude Oil	Excellent	Fair, additives helpful	Excellent
INORGANIC										
Portland Cement based	Calcium Aluminum Silicate	Type I-II,H *G-Ment*, TECT, US Grout	10^{-8}	10^{-6} Not Measured	500–2000	Basic leachate may enhance Be corrosion but also will immobilize $C^{14}O_2$ gas	Limestone	Good, additives helpful	Good, more leach resistant than organic	Fair, material has inherent porosity

Organic grouts do not change the chemistry of the system as cementitious grouts do; thus, any water remaining stays at the same pH, whereas cement would immediately raise the pH of any water remaining after grouting. However, the effect of a raised pH is an effective way to prevent carbon-14 from moving from the Be blocks as $C^{14}O_2$. Any water in contact with cementitious grouts would precipitate the gas to $Ca(C^{14}O_3)$, a process that occurs naturally in the INEEL soil environment (forming the caliche layer).

3.2.4 Long Term Durability

During the grout selection value-engineering meeting (Appendix A), durability of the selected grouts was questioned. Several features of this particular site and organic grouts need to be determined to estimate long-term durability: biodegradation and radiation damage (particularly of organic grouts) and similarity to natural analogs for potential performance over long times (thousands of years) in the environment.

3.2.4.1 Biodegradation. The specific organic grouts field-tested at the INEEL have not been biodegradation tested, which is a measure of biological-attack. Also they have not been tested for gas containment. Biodegradation of somewhat similar plastic polymers has been tested. Polyethylene (saturated organiclike wax) experienced little to no biodegradation and passed the NRC test for low-level waste (Milian 1997). Cementitious agents have been tested for biodegradation (Rogers 1993) and generally pass the NRC biodegradation test unless there is an acidic or high sulfate environment.

3.2.4.2 Radiation Resistance. The radiation readings when six Be blocks were disposed in SVR 20, in 1993, at 3 ft ranged from 180R/hr to 920 R/hr. Since this is from Co-60, it is assumed that the contact at the surface of the blocks is probably in the 10s of R/hr today. The specific organic grouts field-tested at the INEEL have not been radiation tested. As in the case of biodegradation, similar plastic polymers have been tested at very high fields using NRC LLW testing procedures (Franz 1987).

Polyethylene experienced little to no radiation-induced damage and actually increased in strength, because of cross-linking. Polypropylene has been tested at high fields from creep at the INEEL and found again to increase in hardness, but still retains properties sufficient to act as a liner for these Be blocks, were they to be removed and stored in a vault (Nagata 1995). In a listing of plastic resilience to radiation, saturated organic polymers waxlike were rated at an 8 or 9 on a 10-point scale (Knovel 2001). Cement has been used under high-radiation fields since the inception of the nuclear age, and is generally also very resilient to high gamma fields.

The other factor of concern is hydrogen gas generation from containment of radioactive blocks using organic material. Again, specific wax data is unavailable, but the experience with polyethylene indicates hydrogen gas generation from radiolysis should be no more than the tritium already being released from the corrosion of the blocks (Chang 1999). This is in line with the previous polymer tests and indicates that wax, as much as it is similar to plastics, should not be adversely affected by Be block fields. The moisture in cement is also susceptible to hydrogen generation, but this is primarily from significant quantities of alpha emissions.

3.2.4.3 Natural Analog. In the grout selection value-engineering discussion (Appendix A), the long-term durability of the grout was determined a selection criterion. The similarity of a grout to a natural analog gives a qualitative evaluation of its durability in the environment. Each grout has a natural analog indicating that in the type of environment presented by the INEEL site conditions, the grout itself would resist degradation. Natural caliche ($CaCO_3$) found in layers throughout the SDA is a good analog for cement. In the absence of the freeze/thaw damage seen on the surface, and with the slightly alkaline conditions of the subsurface, cement will not degrade in the thousand-year timeframe work suggested.

The Concrete Restorer (polymethacrylate) has an analog in amber, and paraffin waxes exist unchanged in crude oil and tar sands for their geologic life.

3.2.5 Gas Permeability

Gas permeability data is also available for some plastics and cementitious materials (CRC 2001). It is assumed that preventing the corrosion by preventing water intrusion is more likely than forming a gas tight seal with in situ grouting. Polyethylene is similar in its ability—preventing hydrogen and carbon dioxide penetration—to polymethacrylate (Concrete Restorer). As a point of reference, both are better then natural rubber, but slightly more permeable then cellophane. Wax would be the same or better than polyethylene, due to its pliability and self-sealing properties.

4. CONCLUSIONS AND UNCERTAINTIES

In situ grouting technologies have been tested for application in the SDA TRU buried waste to provide a physical barrier to groundwater movement, and also provide mechanical stability to the waste site to prevent subsidence. Of less importance (and greater difficulty to determine) is the grout's ability to physically contain or chemically immobilize hazardous constituents (specifically carbon-14). Both cementitious and wax types of grouts should be fairly effective: the Waxfix being more impermeable to gas and water transport while the cementitious grouts can chemically fix most of the $C^{14}O_2$ before it migrates beyond the grouted zone. All the considered grout materials seem to have long-term stability (thousands of years), being resistant to biodegradation, radiation damage, and having credible natural analogs.

4.1 Implementability Uncertainties

The implementability requirements for in situ grouts center around high-pressure jet grouting. All the selected agents have viscosity less than 30 centipoise, particles not bigger than 3 mm, and set times of at least 2 hours. Waxfix and cementitious grouts both heat the waste up, but do not exceed the boiling point of water. The grouts should not emit vapors above any threshold limits and should not be pyrophoric, explosive, or flammable. The Concrete Restorer that has been field-tested does not meet these criteria. It reacts at temperatures of 116°C and emits a noxious vapor during the reaction. Waxfix and cementitious grouts do not contain toxic substances, nor are they known to react violently with any of the suspected waste material.

Three data gaps and/or uncertainties associated with implementability criteria have been identified:

1. Jet grouting application in LLW type matrices (soil vaults and trenches). This particular matrix does differ from Rocky Flats debris, which has been the focus of past ISG testing. The grouts have not been specifically tested for their encapsulating ability for large metallic objects such as a Be block. The drill will not penetrate the block itself, and the movement of grout around such an object has not been specifically tested. Based on past experience, there will likely be increased grout returns when grouting adjacent to such objects. Metallic LLW debris adjacent to the Be block trench locations should be similar to the simulated waste forms tested previously. But other debris, such as ion exchange resins and "canal debris," have not been specifically simulated during ISG field-testing.

2. Jet grouting in high radiation fields. The shielding effect of grouts has not been evaluated extensively. The cementitious grouts have at least twice the shielding potential than wax-based grouts.

3. Jet grouting with potential gaseous radiological contaminants. Gaseous carbon-14 and tritium are not contained by HEPA filters. The contamination control measures previously developed and tested were focused on particulate contamination control. The grout returns have been shown to contain particulate contaminants, but the grout return effect on radiological gaseous releases is not known.

4.2 Effectiveness Uncertainties

Effectiveness requirements considered for in situ grouts include those developed for TRU waste grouting and others specific to high activity waste and the Be blocks. Grouts must be physically durable under mild solvent and base attack, and wet and dry cycling. They should resist leaching of the grout matrix and of the contained contaminants. Hazardous metals should meet the EPA TCLP criteria and radionuclides the NRC ANS 16.1. Lab hydraulic conductivity should be at least as good as the soil (in this case 10-6 cm/sec) and field hydraulic conductivity no less than that of the surrounding soil. Additionally the grout should not react with Be and should have low gas permeability.

Two data gaps and/or uncertainties associated with effectiveness criteria have been identified:

1. Grout encapsulation of Be. Beryllium is not a primary component of Rocky Flats waste and no testing specific to grout adherence to metallic Be, stopping corrosion of metallic Be in soil, or in situ grout interactions with Be have been performed. Metallic encapsulation and leaching has been tested. To the degree that Be acts as Al for example, these tests have some validity. Cementitious grout chemical interactions with Be have not been tested in a less than saturated soil environment. The wax-based grout appears to microencapsulate better then cementitious grouts. The permeation ability of wax (when molten) allows it to flow to areas beyond the kinetic effect of the jet grout stream.

2. Grout containment of radiological gases. Permeability of the grouts to gases is not known. It is likely that wax grouts are less permeable than cement if it acts like polyethylene. The jet grouting operation will not likely increase gas permeability. Hydraulic conductivity has been tested on the grouts, and the Waxfix is an order of magnitude better then cement at stopping water infiltration.

4.3 Grout Recommendation

Specific treatment requirements for a Be block waste site include a combination of physical barriers to prevent water from getting to the blocks and not precluding their possible future retrieval. All three of the selected grouts have been previously field-tested for suitability to INEEL TRU buried waste. Although previous tests were directed toward buried TRU waste-stabilization goals, they can be generalized for LLW applications and provide sufficient basis for a technical recommendation. For encapsulation of the Be blocks, the Waxfix grout should be superior to other INEEL-tested grouts, based on the past studies.

5. ESTIMATED GROUT VOLUME REQUIREMENTS

In the grout selection value engineering meeting, the grout volume was initially estimated based simply on the disposal volume of the Be blocks. This volume, 121 m^3 (32,000 gal) was well below that in the original engineering estimates of 700 m^3 (187,500 gal). From the large cost range of grouts listed in Table 1, it is apparent that the selection of grout may be partially dependent on the volume required and associated cost. Cementitious grouts are usually under \$1 per gallon even with additives to improve properties. Paraffin grout may be an order of magnitude more costly and a thermoset polymeric grout will be even higher. A detailed grout volume estimate has been undertaken and is outlined below and summarized in Table 6. Appendix B presents detailed volume calculations.

Table 6. Comparison of Be block waste and Waxfix field test pit waste properties.

	Volume (gallon)						Waste Weight (lb)
	Waste	Container	Disposal	Disturbed	Void	Grout	
Test Pit	174	690	1,897	2,845	516	836	3,532
Be Block SVR and Trenches	2,460	12,570	41,405	88,811	38,945	***55,401***	10,454

	Volume (%)							
	Waste/ Container	Container/ Disposal	Disposal / Disturbed	Void/ Disposal	Void/ Disturbance	Grout/ Void	Grout/ Disposal	Grout/ Disturbed
Test Pit	25	36	67	27	18	162	44	29
Be Block SVR and Trenches	20	30	47	94	44	***142***	***134***	***62***

Explanation of Volume Measurements:
Waste = Volume of the actual Waste, Buried Debris type waste in the test pit or Be block waste SV and trenches
Container = Volume of the Containers in which the waste was buried - 1.5 ft× 2.5 ft cardboard drums in the Test Pit, 2.5 ft × 3 ft steel baskets in the Be SV and trenches
Disposal = Volume of the soil vault, trench or pit in which waste was placed
Disturbed = Volume of the soil vault, trench or pit including underburden and overburden
Void = Void volume of waste in soil vault, trench or pit. Disposal Volume minus Waste Volume
Grout = Grout Volume used in field test or estimated quantity based on field test data.

Grout volume was estimated two different ways:

- Comparison of the Be Block waste sites with ISG field tests (Loomis 1997).
- Engineering calculation of the Be block waste site, void fraction, and proposed drilling arrangement.

The grout volume using a comparison with the ISG field test is summarized in Table 6. An estimated 55,400 gal of Waxfix would be required based on previous field experience. Table 6 compares the properties of the ISG field test pit to the Be block soil vaults and trenches (Mullen 2001, Abbot 2003). Using the volumes and properties of this test pit as a basis, a grout volume was estimated using a comparison with properties such as void volume, disturbed volume, and disposal volume.

The grout penetration of undisturbed soil seen in field trials is very minimal, and thus the soil vault and trench boundaries act as a barrier. This barrier effect forces the grout to the surface as grout returns. In the field trial, Waxfix filled over 90% of the container estimated void volume and 70% of the disturbed soil voids. In the test trial holes placed in undisturbed soil, it appeared very little grout went underground, though this was not measured.

The engineering calculation estimates the volume of grout based on that needed to fill the voids in the waste, surrounding debris in the case of the trenches, and disturbed soil. This estimate (very conservative) is over 100,000 gal (Appendix B).

6. REFERENCES

Abbot, D., 2004, Hazard Assessment for Beryllium Block Grouting at the RWMC, (Draft) Rev. 4, HAD-268, pp 1–18.

Adler-Flitton, M. K., C. W. Bishop, R. E. Mizia, L. L. Torres, and R. D. Rogers, 2001, *Long Term Corrosion/Degradation Test Third-Year Results*, INEEL/EXT-01-00036, Rev. 0, Idaho National Engineering and Environmental Laboratory, September 2001.

Burnham, J. B. and M. H. Bartz, 1953, Corrosion of Aluminum and Beryllium by MTR Canal Water, Phillips Petroleum Company Atomic Energy Division. IDO-16055-PPCo, January 14, 1953.

Code of Federal Regulations, 10 CFR 61, “Licensing Requirements for Land Disposal of Radioactive Wastes,” Office of the Federal Register, December 1982.

Chang X, J. A. Laverne, 1999, Molecular Production in the Radiolysis of High Density Polyethylene Radiation Laboratory, Journal Physical Chemistry, Vol. 103, pp 8267–8271, August 1999.

Chemical Rubber Co, 2001, Gas Permeability. 10.6, Fats Oils and Waxes 10.7, CRC-85, 2001.

Department of Energy Idaho Operations Office, INEEL Low-Level Radioactive Waste Acceptance Criteria, DOE/ID-10112, October 2001.

DOE Order 5820.2A, “Management of Low-Level Waste,” Radioactive Waste Management, Chapter III, Department of Energy, September 1989.

Franz, E. M., et al., 1994, Proposed Waste Form Performance Criteria and Testing Methods for Low-Level Mixed Waste, DOE/MWIP-30, Mixed Waste Integrated Program, BNL-52436, August 1994, 100 pp.

Hazard Classification for the In Situ Grouting Cold Test, INEEL/EXT-2000-00638, June 2000.

Franz, E. M, J. H. Heiser, and P. Columbo, 1987, Immobilization of Sodium Nitrate Waste with Polymers, Nuclear Waste Research Group, Brookhaven National Laboratory, BNL-52081, April 1987

Knovel Reference, Chemical Resistance Of Plastics And Elastomers 3rd edition, Knovel - Plastics Design Library Staff, McGraw Hill, 1999.

Loomis, G. G. and D. N. Thompson, 1995a, Innovative Grout/Retrieval Demonstration Final Report, INEL-95/0001, Lockheed Idaho Technologies Company, January 1995.

Loomis, G. G., D. N. Thompson, and J. H. Heiser, 1995b, Innovative Subsurface Stabilization of Transuranic Pits and Trenches, INEL-95/0632, Lockheed Idaho Technologies Company, December 1995.

Loomis, G. G., A. P. Zdinak, and C. W. Bishop, 1997, FY -96 Innovative Subsurface Stabilization Project-Final Report, INEL-96/0439, Lockheed Idaho Technologies Company, July 1997.

Loomis, G. G., A. Zdinak and J. Jessmore, 1999, Acid Pit Stabilization Project (Vol. 1 & 2), INEEL/EXT-98/00009, Lockheed Idaho Technologies Company, March 1999.

Loomis, G., J. Jessmore, et al., 2002, Final Results Report In Situ Grouting Treatability for Application in Buried Transuranic Waste Sites, Volume 1, Technology Description and Treatability Study Results for Operable Unit 7-13/14 Bench-Testing, INEEL/EXT-02-00233, Aug 2002 Rev 0.

Milian, L. W., J. H. Heiser, et al., 1997, In Situ Stabilization of Transuranic/Mixed Waste Project at the INEEL, Environmental And Waste Technology Center, Brookhaven National Laboratory, BNL-64958, August 1997.

Mizia, R. E. et al., 2000, Long Term Corrosion Degradation Test First Year Results, INEEL/EXT-99-00678. September 2000.

Mullen, et. al., 2003, Beryllium Waste Transuranic Inventory in the Subsurface Disposal Area Operable Unit 7-13/14, INEEL EXT 01-01678, March 2003.

Nagata, P. K., 1995, Effects of Gamma Irradiation of High Density Polyethylene, INEL 94/050, Rev.1, July 1995.

NRC, 1991, Technical Position on Waste Form, Rev. 1, Low-Level Waste Management Branch, Nuclear Regulatory Commission, January 1991, p. 20.

Olson, G. L. FY-2002 Environmental Monitoring Report for the Radioactive Waste Management Complex, INEEL/EXT-03-00055, Rev. 0, March 2003.

Rogers, R. D., et al., 1993, Microbial Influence Cement Degradation of Literature Review, INEL for USNRC, NUREG/CR-7987 EGG-2695.

Rogers, R. D., et al., 1993,1994, Microbial Degradation of Low Level Waste, INEL for USNRC, NUREG/CR-6188 Vol 1 EGG-2730, Vol. 2 INEL-95/0153.

Shaw, P., J. R. Weidner, 1996, Laboratory-Performance Criteria for ISTU Waste-Stabilization Materials, INEL-96/0069, March 1997.

Shropshire, K. L., et al, Mission Need Statement: OU 7-13/14 In Situ Grouting Project (Draft), ICP/EXT-03-00084, January 2004 (Draft A).

Weidner, Jerry, et. al. EDF-Biodegradation of Grout, Contaminant Diffusion, Solubility, and Technical Review of the In Situ Grout Treatability Study, INEEL/EXT-2000-00511, March 2000.

WSRC, 1997, Tank Closure Reducing Grout, WSRC-TR-97-0102, Westinghouse Savannah River Company, Aiken, South Carolina.

This page is intentionally left blank.

Appendix A

Phase 1 Grout Selection Decision Meeting Minutes

This page is intentionally left blank.

Appendix A

Phase 1 Grout Selection Decision Meeting Minutes

Date: Tuesday, January 13, 2004 (1:00 – 3:30 p.m)

Attendees: Brandt Meagher, Dan Crisp, Dave Keller, Elden Thompson, Frank Webber, Jim Johnessee, Karen Shropshire, Peter Shaw, Tom Bechtold, Bill Malone, Raj Bhatt, Dave Nickelson, Craig Bean, Darcie Martinson, Liz Branter

Background: The meeting's purpose was to review the grout types being considered for the Be blocks and make a recommendation as to the preferred grout. The project is tasked with grouting locations in the SDA that have Be blocks. The use of jet grouting is assumed. There are 15 discrete locations that have been identified to be grouted. A high-pressure system will be used to make columns of grout.

The project needs to meet the 9/30/04 completion date. That is why the grout already being tested on-site is included in the go/no go criteria.

Hanford and Brookhaven sites may have information on jet grouting, but remember that the soil types are very different from the INEEL soil type.

Assumptions

- All grouts are available within the needed timeframe
- Qualified personnel are available to install the grout (subcontractors)
- Cost could be a go/no go criterion
- 121 m^3 is one estimate of the volume of grout needed.

It was decided that the criteria would not be weighted.

Stopping or limiting corrosion is the main objective for in situ grouting of the Be blocks (per Frank Webber).

Original Criteria

- Field Demonstration
  - The team agreed this should be a "Go/No Go" criteria.
- Implementability (application, regulatory)
  - Material compatibility with waste and soil
  - Heat generation, minimal heat given off during application
  - Hygienically safe and nonhazardous, exhibiting minimal hazardous dust/vapor releases during application, not flammable, corrosive, pyrophoric, explosive, reactive, no listed substances

- Additional interim stabilization/retrievability criteria (fines generation, minimize respirable fines generated upon retrieval)—may need this criteria due to the TRU component.

- Effectiveness criteria
  - Physical or chemical durability, resist subsidence from environmental conditions
  - Resist leaching; radionuclide, stabilization material
  - Hydraulic conductivity
  - Resist biodegradation at site locale under its temperature and moisture conditions (Polymers)
  - Minimal gas generation, chemical, thermal, and radiological
  - Resist (gamma) radiation degradation (this could be a high risk area due to the 1,000R field).

Additional Criteria Discussed

- Longevity
  - All grouts currently being considered should last for more than 1,000 years, but this is difficult to prove regardless of the grout type.

- Cost
  - Cost will be considered separately from the technical criteria.
  - Cost could also be a "Go/No Go" criteria.

- Ability to restore or fix the grout at a later date.

Grout Options Currently Being Considered (that have been field demonstrated at the INEEL)

- Organic
  - 3M Concrete Restorer (thermoset)
  - Waxfix (thermoplastic).

- Inorganic (Portland Cement based)
  - Portland Type I
  - Portland Type H
  - TECT
  - US GROUT
  - GMENT.

Risks/Uncertainties/Data Gaps for Grout Options

- 3M Concrete Restorer
  - Boiling temperature
  - Cost
  - Displacement of tritiated water
  - Safety perception issues (e.g., obnoxious odors)
  - Unknown long-term performance in high gamma field.

- Waxfix
  - Unknown long-term performance in high radiation and high gamma field (this information can be obtained)
  - Only one supplier of the wax
  - Limitation of potential grouting vendors
  - Public perception of the cost versus benefit.
- Portland Cement based grouts
  - Corrosion—Can corrosion be stopped with cementitious material? (There are no testing data on how much corrosion stoppage there is because of the Ph and wet environment. It may or may not fully encapsulate the blocks and thereby preclude water infiltration and corrosion.)
  - Verification that we have encapsulated target (this is usually done by analogies to previous tests)
  - Fracture of concrete may allow for water infiltration
  - Operation difficulties (perceived and real).

Benefit of Waxfix or 3M Concrete Restorer

- Inert, flexible - fills the void and stops corrosion best.

Most Important Uncertainties to Resolve Prior to Making Final Decision

- Possible corrosion issue
- Performance of organic grouts in high gamma field
- Volume of grout needed.

Additional Issues/Risks

- Is it an acceptable risk to pick a grout that can be fixed down the road, if needed?
- Is there a moisture level in the soil that would cause the wax to not work?
- Could the wax just previously injected solidify ahead of the heated wax that is currently being injected?
- Be blocks have not been mocked-up.
- Is a design needed for injection of the grout?

Ideas

- Inject the grout diagonally
- Grout the Be blocks using a combination of both cement and wax.

Conclusions

- The majority of personnel in the meeting prefer the use of wax as the best technical solution to grouting the Be blocks
- Cement is an acceptable grout but risks will need to be assumed (e.g., corrosion uncertainties)
- Once the cost is re-estimated based on volumes of grout needed, the information will be taken to management for their decision.

Actions

- Dave Nickelson will re-evaluate the volume of grout needed
- Tom Bechtold will look for information on wax and a high gamma field
- Dan Crisp will speak with Paul Ritter to work on getting the vault location confirmed.

Appendix B

Be Block Grout Volume Calculation

This page is intentionally left blank.

Appendix B

Be Block Grout Volume Calculation

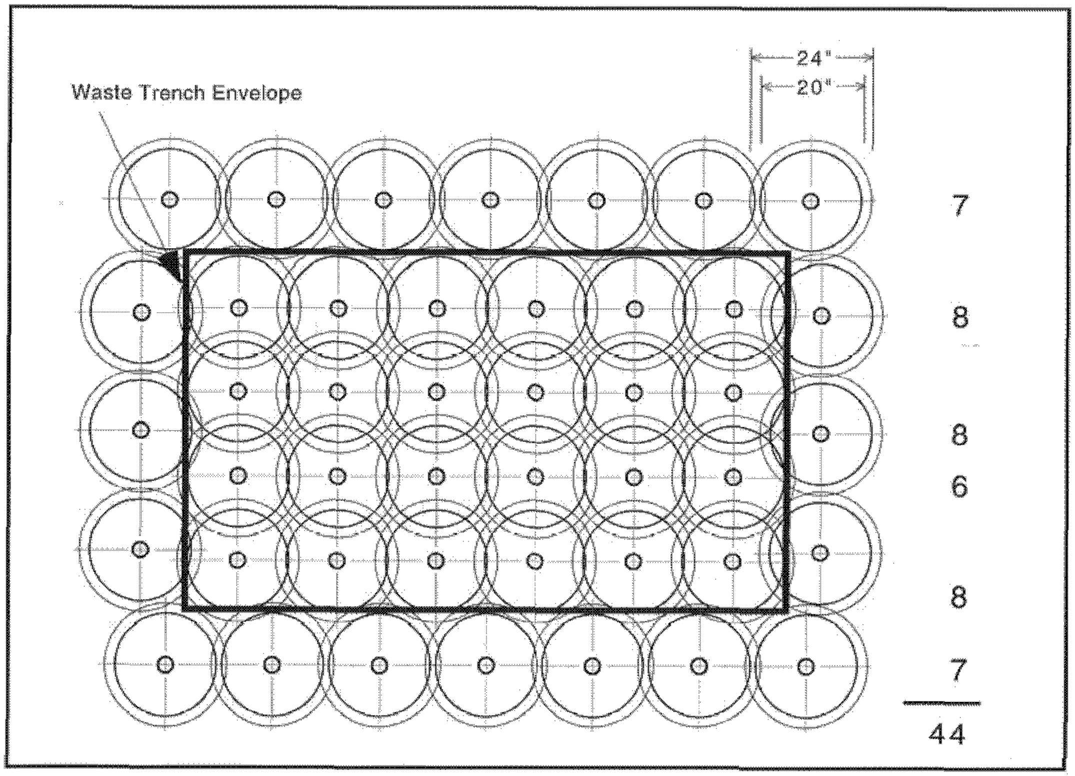
The table below was used to derive the grout volumes that might be required for grouting the Be blocks using Waxfix. Most of the Be block waste disposal data were taken from the Hazard Assessment Document (HAD-268) draft and the Beryllium Waste Transuranic Inventory in the SDA OU 7-13/14 (INEEL/EXT-01-01678). Unit conversion used include: 264 Gal = 1 m^3 = 35.3 ft^3, 7.5 Gal = 1 ft^3.

The engineering estimates are based on the grout insertion hole arrangements shown in the attached diagrams, the voids calculated from waste properties, and an estimate of voids in the surrounding soil. It is assumed that the location of the Be blocks can be determined within a foot.

Feature	Unit	SV 17	SV 20	SVR Subtotal	TRE 52	TRE 54	TRE 58	Trench Subtotal	Total
Locations	#	4	1	5	4	1	5	10	15
Grout Campaigns (estimated)	#	3	1	4	1	1	2	4	8
Depth to Basalt	m	4.6	7.6		6.1	7.6	4.6		
Disposal depth	m	1.8	3.4		3.4	3.4	1.8		
Width or radius	m	0.7	0.7		1.8	1.8	1.8		
Length (Trench)	m				3.0	3.0	3.0		
Waste (Be Block) Volume (per location)	m^3	0.26	0.26		0.79	0.85	0.79		
Basket Volume (per location)	m^3	0.77	0.77		2.30	2.30	2.30		
Disposal Volume (per location)	m^3	2.8	5.2		18.4	18.4	9.7		
Basket Volume per Disposal Volume	%	83	88		88	88	87		
Waste Volume per Disposal Volume	%	9.6	5.1		4.3	4.6	8.2		
Waste Volume per Basket Volume	%	35	35		34	37	34		
Absolute Void in vault or trench	%	90.4	94.9		95.7	95.4	91.8		
Vault or Trench Volume (disturbed)	gal	7439	3099	10,538	34788	10871	32614	78,274	88,811
Total Disposal Volume	gal	2929	1383	4,311	19403	4851	12840	37,094	41,405
Total Disposal Void Volume	gal	2649	1313	3,962	18565	4626	11793	34,984	38,945
Disposal and Disturbed Volume (33% Void)	gal	4230	1902	6,132	23919	6687	18664	49,269	55,401
Total Volume (19 Hole-SV and 44 Hole –Trench, 33% void)	gal	8841	3684	12,525	27298	8531	25592	61,421	73,945
Total Volume (82gal/hole and 44 holes/location, 50% void)	gal	23995	9998	33,992	31993	9997.8	29993	71,984	105,976

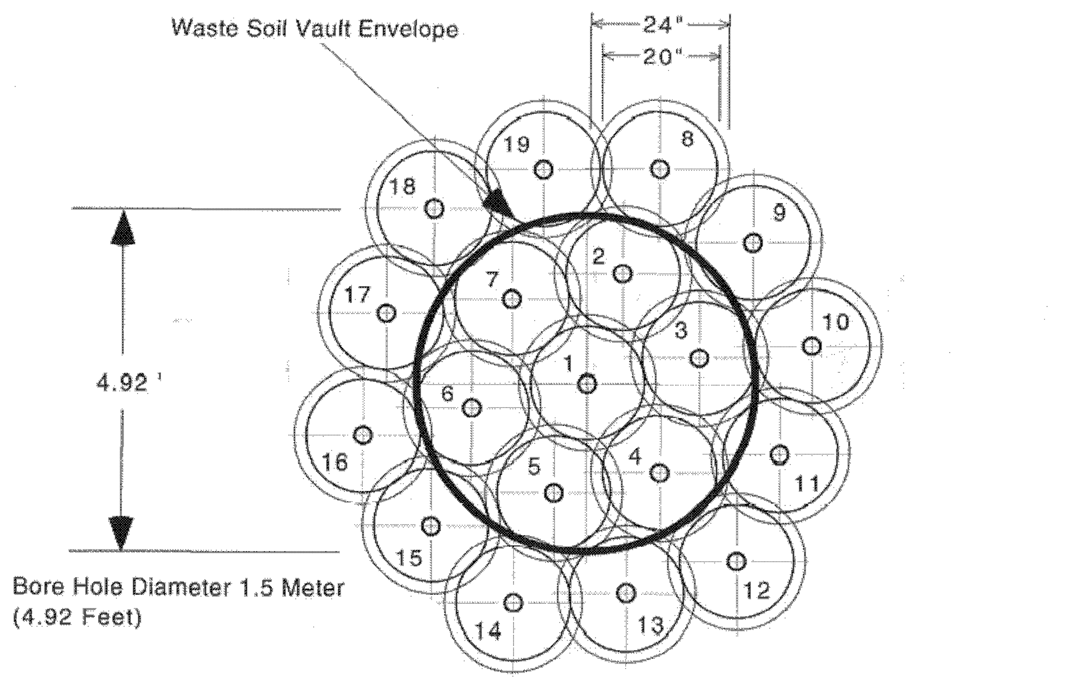
The grout drilling matrices shown in the pictures below were used to establish the number of drill stem insertions required to in situ grout the various configurations of Be blocks. The trenches are estimated to take 44 insertions using a body centered arrangement. This gives an entire row of columns outside the trench area.

44 Injection Points For a 3.0M (9.84 Ft) x 1.8M (5.9 Ft) Trench



The Soil Vaults are estimated to take 19 insertions. Again, this gives an entire row of columns outside the soil vault area.

19 Injection Points Per Bore Hole



The sequence for the drill injection points starts in the center, then completing each ring of columns before starting the next ring. (The numbers illustrate the drill injection sequence.)